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Composition of Automobile Evaporative and Tailpipe Hydrocarbon Emissions

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16. ABSTRACT

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Composition of Automobile Evaporative and Tailpipe Hydrocarbon Emissions

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Mathematical modeling of ambient air photochemistry requires comprehensive mobile source hydrocarbon emission speciation. Passenger car tailpipe and evaporative hydrocarbon emissions have been examined using procedures described in the Federal Register for emissions certification. Hydrocarbon emission rates and compositions were determined for four passenger cars: a 1983 Chevrolet, a 1977 Ford Mustang II, a 1978 Mercury Monarch, and a 1979 Ford LTD-II. These vehicles are representative of a wide range of exhaust and evaporative emissions control configurations. Both emission rates and compositions were dependent on the emissions control devices used with the vehicles, and the fuel composition and vapor pressure. In agreement with the literature, tailpipe catalyst control systems removed unsaturated olefinic, aromatic, and acetylenic hydrocarbons to a greater extent than saturated paraffinic hydrocarbons. The impact of evaporative control devices on composition was not well defined, however the limited data suggested a sensitivity to fuel aromatic content. The emission rate of benzene, emphasized because of its potential carcinogenicity, was sensitive to both fuel benzene and total aromatic content.

The growing sophistication of mathematical models of atmospheric photochemistry has increased the need for detailed identification of ambient air hydrocarbon compounds. Efforts to establish source inventories of individual hydrocarbon emissions have identified a lack of speciation data for passenger car evaporative emissions,[1] although a significant amount of data have been published characterizing tailpipe emissions from vehicles with a wide variety of emissions control systems.[2-8] The rates and patterns of motor vehicle hydrocarbon emissions vary significantly with the fuel, driving patterns, ambient conditions, and the types of emissions control systems used. The control of hydrocarbon emissions from passenger cars has taken many forms since 1968. Crankcase emissions were essentially eliminated through use of positive crankcase ventilation technologies. Tailpipe emissions have been dramatically reduced with a variety of catalyst technologies, and evaporative emissions have been reduced through use of adsorption-regeneration carbon canister technologies. Generally the catalyst systems used on passenger cars for tailpipe hydrocarbon emissions reduction preferentially oxidize unsaturated hydrocarbons.[7,8] Thus, the photochemical reactivity of the hydrocarbon mixture as well as the mass of hydrocarbons emitted are reduced by the catalyst. The impact of evaporative control devices on hydrocarbon emissions will be examined in this paper.

To define the composition of the aggregate hydrocarbon emissions from automobiles, the evaporative emissions must be considered.[9,10] Depending on the varying degrees of control, for some model years the evaporative hydrocarbon emissions may account for nearly one-half of the hydrocarbon mass being emitted from the automobile. Throughout this presentation, reference to evaporation emissions will include only those emissions associated directly with the vehicle and not those associated with refueling.

Table I presents a chronology of automobile regulatory standards for tailpipe and evaporative hydrocarbon emissions. As the tailpipe standards are based on gram/mile emissions and the evaporative on gram/test emissions, the relative contribution of each to the aggregate is not readily apparent. The defined test procedure for determining evaporative emissions develops a diurnal and hot soak mass emission factor.[11] To permit comparison with tailpipe emissions, the diurnal and hot soak factors are generally combined as in equation (1) to give "g/mi" evaporative hydrocarbon rates:[12]

$$\text{Evap} = \frac{\text{Di} + 3.3\ \text{trips/day}\ (\text{Hs})}{29.4\ \text{miles/day}} \quad (1)$$

Evap = total evaporative emissions, grams/mile

Di = diurnal evaporative emissions, grams/day

Hs = hot soak evaporative emissions, grams/trip

For example, a passenger car certifying at 6 g/test (3 g diurnal, 3 g hot soak), would be emitting the equivalent of 0.44 g/mile.

As indicated in Table I, the evaporative standard increased from 2 to 6 g/test for the 1978 model year. This increase

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resulted from a change in the procedures used to determine evaporative emissions.[11] Prior to 1978, vehicles were certified at 2 g/test with a "carbon trap method" which dramatically underestimated actual emissions. A survey of in-use vehicles certified using this procedure indicated an actual emissions level of about 24 g/test as measured using the "Sealed Housing for Evaporative Determination" (SHED) method.[12] The SHED system encloses the entire motor vehicle while evaporative emissions are being determined. This procedure has been used for evaporative determination since the 1978 model year. Most of the detailed hydrocarbon evaporative data developed prior to 1978 using trapping techniques characterized isolated sources of emissions, e.g. the carburetor or fuel tank, but not the entire vehicle system as with the SHED.[13-15] Mathematical manipulations have also been used to predict evaporative emissions characteristics as a function of fuel composition.[13,16]

Historically, emphasis on hydrocarbon emissions from motor vehicles has been primarily directed at determining photochemical reactivity. More recently, however, interest has been expressed in the emission rate of individual components because of their potential toxicity or carcinogenicity. Benzene was listed as a hazardous pollutant under Section 112 of the Clean Air Act, but only very limited data are available detailing vehicle aggregate benzene emissions (evaporative and tailpipe).[17-19] This study examined the speciation of tailpipe and evaporative hydrocarbon emissions as a function of vehicle configuration and fuel. The paraffinic, olefinic, acetylenic, and aromatic content of each is presented along with the content of single hydrocarbon species of particular interest. Benzene emissions are reported for each vehicle and fuel tested. The sensitivity of emissions to fuel benzene content is examined by varying the benzene level of individual fuels. Speciation data for over 60 compounds are available from the author on request.

Detailed hydrocarbon emissions inventories for passenger cars are not abundant in the literature, particularly so for evaporative sources and care must be exercised when applying the available data. Speciation of hydrocarbon emissions is sensitive to many variables, including fuel composition, emissions control configuration, driving patterns, and ambient temperature. The limited reported studies have examined limited ranges of these important variables. The data reported in this document describe hydrocarbon emissions from four passenger cars, for one driving pattern, under summer temperature conditions. Four fuels were used in the study. Extrapolation from a limited data base to vehicle fleet emissions character is difficult.

Evaporative and tailpipe hydrocarbon emissions have significantly different speciation. Further, they are emitted under different operating conditions. Evaporative emissions from recent generation passenger cars are inconsequential while the vehicle is being operated over the highway. Thus, evaporative speciation will be important to urban grid areas dominated by parking lots and tailpipe speciation to those dominated by moving vehicles on streets and highways. Fuel composition is very important to emissions speciation of hydrocarbons of the molecular weight of butane and higher. Typically, marketed gasolines will range in aromatic hydrocarbon content from about 20 to 50%. Vapor pressure and distillation characteristics vary significantly. This is a primary source of variability between reported emissions factors for individual hydrocarbons and those experienced in actual urban areas. Tailpipe hydrocarbon speciation also varies significantly with emission control configurations.

When attempting to define the composition of hydrocarbon emissions from passenger cars in urban areas, extrapolation from the literature must consider fuel composition, vehicle configurations, driving patterns, and ambient conditions.

Table I. Automobile hydrocarbon emissions standards (49-state Federal).

Model Year	Tailpipe, g/mile	Evaporative, g/test
1972–74	3.4	2
1975–77	1.5	2
1978–79	1.5	6[a]
1980	0.41	6
1981–83	0.41	2

[a] Begin use of SHED test procedure.

Table II. Test vehicle specifications.

Vehicle	Engine	Mileage	Test inertia wt.	Emission control
1963 Chevrolet	283V8	66,500	3000	PCV
1977 Mustang	302V8	<10,000	3000	EGR/CAT/PCV/fuel tank canister
1978 Monarch	302V8	<10,000	3500	EGR/AIR/CAT/PCV/carb and fuel tank canister[a]
1979 LTD-II	351V8	<10,000	4500	EGR/AIR/CAT/PCV/carb and fuel tank canister[b]

[a] A single canister used for control of both fuel tank and carburetor emissions.
[b] Two canisters, one each for the fuel tank and carburetor, used for control of emissions.

Experimental Methods

The test vehicles selected for this study covered a range of emissions control systems, with particular emphasis on evaporative systems. A 1963 Chevrolet was chosen as an example of pre-control vehicles, a 1977 Ford Mustang II as representative of the last model year certified with the "carbon trap method," and a 1978 Mercury Monarch and 1979 Ford LTD-II as representative of current generation systems. For the 1977 configuration, only fuel tank emissions were controlled by the evaporative canister. A major difference between the 1978 and 1979 vehicles was the use of a single carbon canister for emissions from the fuel tank and carburetor with the 1978 Monarch, and two canisters, one each for the fuel tank and carburetor

Table III. Test fuel specifications.

Fuel	A	A-1	B	B-1	C	D[a]	D-1
RVP	8.4		9.8		12.3	12.8	
API gravity	61.6		54.9		62.0	62.3	
Distillation, °F							
10%	133		126		114	108	
50%	207		219		219	217	
90%	285		327		362	347	
EP	376		369		410	418	
Hydrocarbon, wt. %[b]							
n-butane	3.73		3.48		9.94	9.85	
i-pentane	6.94		11.19		7.85	8.15	
n-pentane	5.48		3.40		4.13	4.08	
benzene	0.28	7.1	1.52	7.1	1.95	1.83	5.8
toluene	17.55		27.91		6.30	6.01	
paraffinic	65.4		49.0		67.0	69.0	
olefinic	7.2		7.6		7.0	5.1	
aromatic	27.4		43.4		25.7	25.9	

[a] Leaded gasoline 1.98 g/gal.
[b] Analysis by gas chromatography.

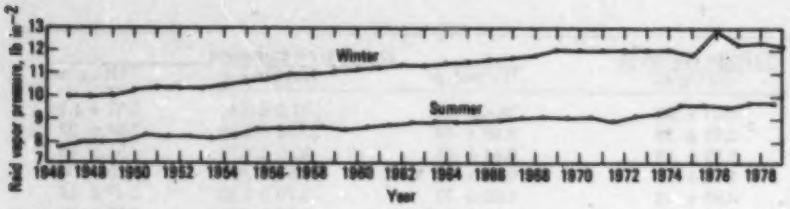

Figure 1. Gasoline vapor pressure trends.

with the 1979 Ford LTD-II. Table II gives additional details for the four test vehicles.

Four primary fuels were used. All were commercially available gasolines. Table III presents specifications for each. Fuels A and C were regular grade unleaded, summer and winter, respectively. Fuel B was a premium grade summer unleaded, and Fuel D regular grade winter leaded. Fuels A, B, and D were also tested with added benzene to examine the sensitivity of benzene emissions to fuel benzene content.

Test Procedure for exhaust emissions certification, was used to prepare the vehicle for the hot soak test and to provide tailpipe emissions typical of city driving patterns. The only deviation from the described procedures is the use of actual individual hydrocarbon density values (grams per cubic foot) rather than the assumed average value given in the Federal Register for calculations of total hydrocarbon mass emissions. The reported total hydrocarbon rates are based on summation of the individual hydrocarbon rates.

Table IV. Vehicle-test fuel combinations.

Vehicle	FUEL						
	A	A-1	B	B-1	C	D	D-1
1963 Chevrolet						X	X
1977 Mustang			X	X	X		
1978 Monarch	X	X	X		X		
1979 LTD-II			X	X	X		

Typical commercial fuel benzene content is less than 2%.[18-21] Vapor pressures varied from 8.4 lb Reid Vapor Pressure (RVP) to 12.8 lb RVP. The national average gasoline RVP has shown steady increase since 1946, as indicated in Figure 1, with the current summer level about 9.8 lb and winter level about 12.3 lb RVP (evaporative certification is based on fuel RVP values from 8.7–9.2 lb).[11,20] The test fuel aromatic content varied from 25.7 to 43.4 weight %. Hydrocarbon emissions characteristics are very sensitive to fuel chemical composition, vapor pressure, and the ASTM distillation curve. Table IV describes which fuels were used with each test vehicle.

The vehicle test procedure is graphically illustrated in Figure 2. The details of the vehicle preconditioning, diurnal evaporative test, cold start exhaust test, and hot soak evaporative test are given in the Federal Register.[11] The diurnal test simulates emissions experienced during fuel system heat buildup resulting from daily night to afternoon ambient temperature increases. Only the fuel tank "sees" the temperature increase of 60° to 84° F in the defined test procedure. The hot soak test simulates emissions experienced on parking the car after an urban driving period. The Urban Dynamometer Driving Schedule, normally used in the Federal

Hydrocarbon samples for chromatographic analysis were collected in Teflon (E.I. duPont de Nemours and Co.) film bags from the SHED, which encloses the vehicle during evaporative testing. Similarly, exhaust samples were collected in Teflon bags from the constant volume sampling apparatus which is normally used for sampling automobile exhaust during certification of tailpipe emissions.[11] The Teflon film bags were used to transport the samples for gas chromatographic analysis of the individual hydrocarbon species. The gas chromatographic analytical procedures have been previously described.[7,23] All reported data are arithmetic mean values from two or more tests.

Results

One objective of this study was to examine the relative contribution of the tailpipe and evaporative hydrocarbon emissions to the aggregate from the vehicle. Table V presents tailpipe and evaporative hydrocarbon emission factors for the vehicles examined over the range of fuels tested. As indicated, the evaporative emissions are very sensitive to fuel characteristics. The ambient temperature levels encountered by the vehicles were 68° to 86°F, as prescribed by the Federal Register.[11] Figure 1 suggests that 9.8 lb would be a reasonable fuel RVP for these conditions.

The 12.8 lb RVP leaded fuel used with the 1963 Chevrolet resulted in overestimation of the evaporative emissions for the test ambient conditions. A reduction in RVP from 12.8 to 9.8 lb would reduce evaporative emissions from this vehicle substantially. A reduction of about ⅓ was suggested by the Mustang hot soak, conditions most closely approximating the Chevrolet conditions. An evaporative rate of about 3.7 g/mi would be appropriate for the Chevrolet with a 9.8 RVP fuel. Assuming no significant sensitivity of the tailpipe emissions to fuel RVP, the evaporative emissions from the 1963 Chevrolet would constitute about 48% of the aggregate emissions. The 1977 Mustang data suggest that about 49% of the aggregate emissions are evaporative. However, the tailpipe hydrocarbon emissions from this vehicle exceeded the certification value of 1.5 g/mi due to a carburetor malfunction. Certification level tailpipe emissions would suggest about 64% of the Mustang aggregate hydrocarbon emissions to be from evaporative sources. As indicated, the major source of evaporative hydrocarbon emissions from 1972 to 1977 vehicles was hot soak, carburetor emissions. The evaporative canister collects only fuel tank emissions in this configuration.

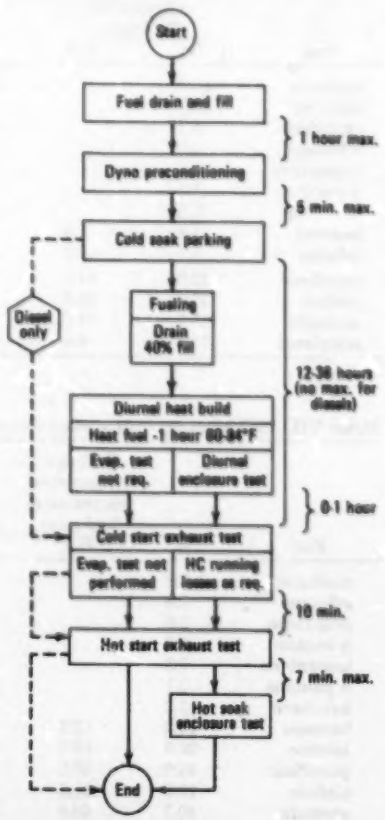

Figure 2. Vehicle test sequence.

Table V. Aggregate hydrocarbon emission rates.

Vehicle	Fuel (RVP)	Tailpipe emissions THC, g/mi	Evaporative emissions Diurnal, g	Evaporative emissions Hot Soak, g	Evaporative emissions THC, g/mi
1963 Chevrolet	D (12.8)	4.03 ± .06	38.8 ± 2.8	37.2 ± 9.4	5.57 ± 1.18
1977 Mustang	B (9.8)	2.78 ± .32	0.48 ± .04	23.48 ± 1.99	2.65 ± .23
	C (12.3)	2.80 ± .13	0.44 ± .01	32.0 ± 4.95	3.61 ± .56
1978 Monarch	A (8.4)	1.03 ± .12	0.54 ± .15	1.64 ± .32	0.20 ± .04
	B (9.8)	0.89 ± .12	1.62 ± .77	3.79 ± 1.32	0.47 ± .16
	C (12.3)	1.27 ± .18	10.93 ± 7.47	3.36 ± .58	0.75 ± .29
1979 LTD-II	B (9.8)	0.48 ± .14	2.05 ± 1.2	2.18 ± .19	0.31 ± .06
	C (12.3)	0.51 ± .13	30.3 ± .3	12.1 ± 3.0	2.39 ± .32

The 1978 Monarch and 1979 LTD-II with the more advanced evaporative control systems, had 35% and 39%, respectively, of their aggregate hydrocarbon emissions from evaporative sources.

The evaporative emissions constitute a significant fraction of the total hydrocarbon emissions from all of the tested vehicles. Final hydrocarbon standards, 0.41 g/mi tailpipe and 2.0 g/test evaporative (approximately equal to 0.15 g/mi), would suggest an ultimate condition where about 27% of the total aggregate hydrocarbon emissions originate from evaporative sources. Note that evaporative emissions vary significantly with fuel vapor pressure and that the historical trend has been to increased fuel vapor pressure, as illustrated in Figure 1.

The relative abundances of tailpipe and evaporative hydrocarbon emissions suggest that both need be considered when developing speciation data for motor vehicle sources. Tables VI, VII, VIII, and IX present detailed hydrocarbon compositions for emissions from the 1963 Chevrolet, 1977 Mustang, 1978 Monarch, and 1979 LTD-II, respectively. The sensitivity of benzene emissions to fuel benzene level is presented as a special case, due to current interest in this potentially carcinogenic compound.

The similar hydrocarbon composition and vapor pressure of fuels C and D permitted examination of the impact of emission control technology on hydrocarbon emissions for the full range of vehicles studied. As indicated in Table X, when tailpipe total hydrocarbon levels were reduced, the paraffinic fraction of the total increased. The tailpipe catalyst systems generally had greater activity for the removal of olefinic hydrocarbon compounds from the exhaust stream than paraffinic hydrocarbon compounds. The evaporative control systems did not appear to alter the composition of the emissions significantly with reduction in mass for the regular grade fuels tested. However, this observation was not clear for the premium grade, high aromatic unleaded fuel tested. As indicated, the relative aromatic content of the evaporative emissions for fuel B increased with decreases in total mass.

Including evaporative hydrocarbon emissions in the vehicle aggregate generally increased the relative abundance of the paraffinic hydrocarbon compounds, primarily because the evaporative emissions were dominated by the low molecular weight paraffinic components of the fuel. Uncombusted fuel was responsible for a majority of the aggregate hydrocarbon emissions above

Table VI. 1963 Chevrolet hydrocarbon emissions composition.

Fuel	Tailpipe hydrocarbon composition, % of total D	Tailpipe hydrocarbon composition, % of total D-1	Evaporative hydrocarbon composition, % of total D	Evaporative hydrocarbon composition, % of total D-1	Aggregate hydrocarbon composition, % of total D	Aggregate hydrocarbon composition, % of total D-1
methane	10.2		0.0		4.3	
ethylene	13.5		0.0		5.7	
propylene	5.7		0.0		2.4	
n-butane	4.0		29.2		18.6	
isopentane	3.1		16.9		11.1	
n-pentane	1.7		6.3		4.4	
isooctane	2.2		1.9		2.0	
benzene	3.8	7.0	0.6	3.6	1.9	5.2
toluene	5.1	5.2	1.7	1.3	3.1	3.1
paraffinic	42.0	41.3	87.6	85.6	68.4	64.8
olefinic	27.1	26.3	8.1	8.0	16.1	16.6
aromatic	20.7	24.0	4.3	6.4	11.2	14.6
acetylenic	10.2	8.4	0.0	0.0	4.3	4.0

Table VII. 1977 Mustang hydrocarbon emissions composition.

Fuel	Tailpipe hydrocarbon composition, % of total B	Tailpipe hydrocarbon composition, % of total B-1	Tailpipe hydrocarbon composition, % of total C	Evaporative hydrocarbon composition, % of total B	Evaporative hydrocarbon composition, % of total B-1	Evaporative hydrocarbon composition, % of total C	Aggregate hydrocarbon composition, % of total B	Aggregate hydrocarbon composition, % of total B-1	Aggregate hydrocarbon composition, % of total C
methane	8.8		9.8	0.0		0.0	4.5		4.3
ethylene	7.4		10.6	0.0		0.0	3.8		4.7
propylene	2.6		3.8	0.0		0.0	1.3		1.7
n-butane	2.3		5.7	12.0		21.1	7.1		14.4
isopentane	7.3		5.1	28.5		17.0	17.7		11.8
n-pentane	2.1		2.5	7.9		7.3	4.9		5.2
isooctane	2.2		4.2	1.7		3.1	2.0		3.6
benzene	10.5	12.9	6.8	1.8	6.2	1.6	6.2	10.0	3.9
toluene	20.8	18.3	6.0	8.3	8.6	2.2	14.7	14.1	3.9
paraffinic	43.2	40.2	54.7	75.1	71.5	82.4	58.8	53.7	70.2
olefinic	16.0	18.5	21.6	11.5	11.8	11.4	13.8	15.6	15.9
aromatic	40.7	40.5	23.4	13.4	16.7	6.1	27.3	30.3	13.7
acetylenic	0.2	0.8	0.3	0.0	0.0	0.0	0.1	0.5	0.1

Table VIII. 1978 Monarch hydrocarbon emissions composition.

Fuel	Tailpipe hydrocarbon composition, % of total				Evaporative hydrocarbon composition, % of total				Aggregate hydrocarbon composition, % of total			
	A	A-1	B	C	A	A-1	B	C	A	A-1	B	C
methane	10.3		9.6	8.7	0.0		0.0	0.0	8.7		6.2	5.5
ethylene	4.8		4.1	5.5	0.0		0.0	0.0	4.0		2.7	3.5
propylene	2.5		2.2	2.3	0.0		0.0	0.0	2.1		1.4	1.5
n-butane	4.4		4.7	14.0	14.0		6.6	49.9	5.9		5.4	27.3
isopentane	6.1		10.8	7.0	15.8		20.3	9.3	7.7		14.1	7.9
n-pentane	4.7		2.8	2.9	11.3		5.9	3.6	5.8		3.9	3.2
isooctane	8.0		2.5	3.8	5.4		2.4	1.2	7.6		2.5	2.8
benzene	2.9	6.6	3.4	2.6	0.5	5.7	1.8	0.6	2.5	6.4	2.8	1.9
toluene	11.3	10.4	17.7	4.1	7.0	6.2	20.3	1.7	10.6	9.6	18.6	3.2
paraffinic	60.8	57.9	56.0	63.7	80.1	76.6	61.0	88.0	63.9	61.3	57.7	72.7
olefinic	18.6	18.7	13.9	18.6	8.7	9.4	10.1	7.3	17.0	17.0	12.6	14.4
aromatic	20.1	22.1	28.7	14.2	11.2	14.0	28.9	4.7	18.7	20.6	28.8	10.7
acetylenic	0.5	1.3	1.4	3.5	0.0	0.0	0.0	0.0	0.4	1.1	0.9	2.2

carbon number 4, the combustion process below carbon number 4.

The benzene emissions from the test vehicles were sensitive to fuel composition. Because the only source of benzene for evaporative emissions was the fuel, the fuel benzene level had a more significant impact on the evaporative emissions rates than tailpipe rates, while the combustion process was a significant additional source for tailpipe emissions. Combustion chemistry can produce benzene from fuel components other than benzene, as was particularly evident with the 1977 Mustang which was operating under higher than normal fuel/air ratios (See Table XI). Fuels B and C had similar levels of benzene, 1.52 and 1.95%, respectively, but significantly different levels of aromatic components, 43.4% and 25.7%, respectively. Tailpipe benzene rates were substantially higher for fuel B than fuel C. Dealkylation of higher aromatics appears an important process under fuel rich combustion conditions. It was not an important process under the operating conditions of the 1978 Monarch. Evaporative sources accounted for 3 to 46% of the total benzene emitted from the tested vehicles over the range of conditions examined.

The modified fuels (A-1, B-1, D-1) contained more benzene than normally marketed gasolines, and further demonstrated the importance of fuel benzene to tailpipe and evaporative emission rates. The evaporative benzene emissions were more sensitive to fuel benzene content than were the tailpipe emissions.

Conclusions

With the vehicles and fuels examined, hydrocarbon emissions were sensitive to emissions control configuration and fuel composition. Catalytic tailpipe control systems reduced total hydrocarbon mass, the unsaturated hydrocarbon compounds to a greater extent than the saturated compounds. Evaporative control devices also reduced total hydrocarbon mass, but their impact on composition was not clear. Evaporative emission rates increased with increased fuel vapor pressure, and the trend in marketed gasolines during the last 30 years has been to increased vapor pressure.

Evaporative sources constituted a significant fraction of the total vehicle aggregate hydrocarbon emissions, varying from about ⅓ to ½ with the vehicles tested. The inclusion of evaporative sources in the definition of the composition of hydrocarbon emissions from motor vehicles resulted in an increased relative abundance of paraffinic hydrocarbon compounds. Generally, low molecular weight paraffinic compounds (butanes and pentanes) are used commercially for maintenance of fuel vapor pressure, and these compounds dominated the evaporative emissions.

Benzene emissions from motor vehicles were sensitive to fuel composition. Both fuel benzene and total aromatic content influenced the emission rate of benzene. Dealkylation of higher aromatics appeared a significant source of tailpipe benzene under some vehicle operating conditions. The contribution of evaporative sources was less than tailpipe, but significant, about 20% of the total aggregate benzene, under normal operating conditions.

Table IX. 1979 LTD-II hydrocarbon emissions composition.

Fuel	Tailpipe hydrocarbon composition, % of total			Evaporative hydrocarbon composition, % of total			Aggregate hydrocarbon composition, % of total		
	B	B-1	C	B	B-1	C	B	B-1	C
methane	25.8		40.8	0.0		0.0	15.7		7.3
ethylene	3.8		4.8	0.0		0.0	2.3		0.9
propylene	1.6		1.6	0.0		0.0	1.0		0.3
n-butane	2.3		5.3	10.1		43.0	5.3		36.2
isopentane	5.8		3.9	15.0		3.3	9.4		3.4
n-pentane	1.4		1.7	3.8		12.0	2.3		10.2
isooctane	2.0		3.2	2.2		1.5	2.1		1.8
benzene	5.1	7.0	2.8	2.2	7.1	0.5	4.0	7.0	0.9
toluene	15.9	13.9	2.8	21.7	22.8	1.0	18.2	17.2	1.3
paraffinic	58.3	61.0	72.8	57.1	49.3	89.9	57.8	56.6	86.8
olefinic	10.9	11.6	11.6	8.1	7.7	7.7	9.8	10.2	8.4
aromatic	29.9	26.5	11.0	34.8	43.0	2.4	31.8	32.6	4.0
acetylenic	0.9	0.9	4.6	0.0	0.0	0.6	0.6	0.6	0.8

Table X. Impact of emission control technology on hydrocarbon composition.

	Tailpipe Emissions			
	1963 Chevrolet[a]	1977 Mustang[b]	1978 Monarch[b]	1979 LTD-II[b]
paraffinic, %	42.0	54.7	63.7	72.8
olefinic, %	27.1	21.6	18.6	11.6
aromatic, %	20.7	23.4	14.2	11.0
acetylenic, %	10.2	0.3	3.5	4.6
THC, g/mi	4.0	2.8	1.3	0.5
	Evaporative Emissions			
	1963 Chevrolet[a]	1977 Mustang[b]	1978 Monarch[b]	1979 LTD-II[b]
paraffinic, %	87.6	82.4	88.0	89.9
olefinic, %	8.1	11.4	7.3	7.7
aromatic, %	4.3	6.1	4.7	2.4
THC, g/mi	5.6	3.6	0.8	2.4
		1977 Mustang[c]	1978 Monarch[c]	1979 LTD-II[c]
paraffinic, %		75.1	61.0	57.1
olefinic, %		11.5	10.1	8.1
aromatic, %		13.4	28.9	34.8
THC, g/mi		2.7	0.5	0.3

[a] Fuel D.
[b] Fuel C.
[c] Fuel B.

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Table XI. Passenger car benzene emissions.

Vehicle	Code	Fuel aromatic, %	benzene, %	Tailpipe benzene, Mg/mi	Evaporative benzene, Mg/mi	Aggregate benzene, Mg/mi
1963 Chevrolet	D	25.9	1.8	153	33	186
	D-1	28.9	5.8	327	192	519
1977 Mustang	B	43.4	1.5	292	48	340
	B-1	46.6	7.1	397	146	543
	C	25.7	2.0	190	58	248
1978 Monarch	A	27.4	0.3	30	1	31
	A-1	32.4	7.1	58	11	69
	B	43.4	1.5	30	9	39
	C	25.7	2.0	33	5	38
1979 LTD-II	B	43.4	1.5	25	7	32
	B-1	46.6	7.1	35	21	56
	C	25.7	2.0	14	12	26

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